VEGETATION OF THE KALINZU FOREST, UGANDA: ORDINATION OF FOREST TYPES USING PRINCIPAL COMPONENT ANALYSIS

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ABSTRACT We analyzed the vegetation of the Kalinzu Forest, Uganda, using principal component analysis. We got two components by the analysis: one seemed to indicate the strength of environmental factors characteristic to the western part of the study area, and the other seemed to indicate the extent of disturbance by human exploitation. Using these components, we made a vegetation map that distinguished four types of vegetation: mixed mature forest, *Parinari*-dominated mature forest, *Parinari*-dominated secondary forest, and *Musanga*-dominated secondary forest. Preliminary analysis of the relationship between vegetation type and frequency of vocalization of chimpanzees suggested that these components would give important information for the study of habitat use by chimpanzees.

Key Words: Principal component analysis; Vegetation type; Ordination; the Kalinzu Forest; Tropical forest; Chimpanzee.

INTRODUCTION

We have been conducting ecological studies of six species of primates, including *Pan troglodytes, Cercopithecus ascanius, C. mitis, C. lhoesti, Colobus guereza*, and *Papio anubis* in the Kalinzu Forest Reserve, Uganda, since 1992 (Hashimoto, 1995, 1998). One of the main purposes is to clarify the relationship between the ecology of primates and forest structure, and such studies require a vegetation map of the study area. Without precise information about the vegetation of habitat, it is impossible to clarify the subsistence mechanisms of subject species. It is especially important to know the distribution of each type of vegetation in the study of animals, such as chimpanzees, whose ranging area is wide enough to cover different types of vegetation.

There are a number of methods available for vegetation mapping: from visual estimate to remote sensing by satellite image (Bullock, 1996). In the case of vegetation mapping using a systematic sampling method such as transect or quadrant, vegetation type is often analyzed by ordination or classification (Pielou, 1969, 1984; Kobayashi, 1995).

Ordination of vegetation has been developed for the analysis of vegetation that changes continually according to environmental gradients (Pielou, 1969; Kobayashi, 1995). Ordination is better than classification because there is no need to set any criteria to prescribe classes (Pielou, 1969). In this study, we made a systematic census of trees, and made a principal component analysis for the ordination of vegetation. We also analyzed relationships between environmental gradient and habitat use by chimpanzees, to give an example for application of the principal component analysis.

Even if the ordination may be a better way to analyze the continuously changing vegetation, discrete mapping of vegetation is also useful for the ecological studies of animals. This study will, therefore, try to make an objective vegetation map by using the scores of principal component analysis.

MATERIALS AND METHODS

The Kalinzu Forest Reserve, covering an area of 137 km^2, lies in western Uganda (30° 07'E, 0° 17'S: Howard, 1991). It is contiguous to the Maramagambo Forest, which is a part of Queen Elizabeth National Park, and the total area of these two forests is 580 km^2. There are two rainy seasons (from the middle of March to the end of May, and from the middle of September to the end of December), and two rela-

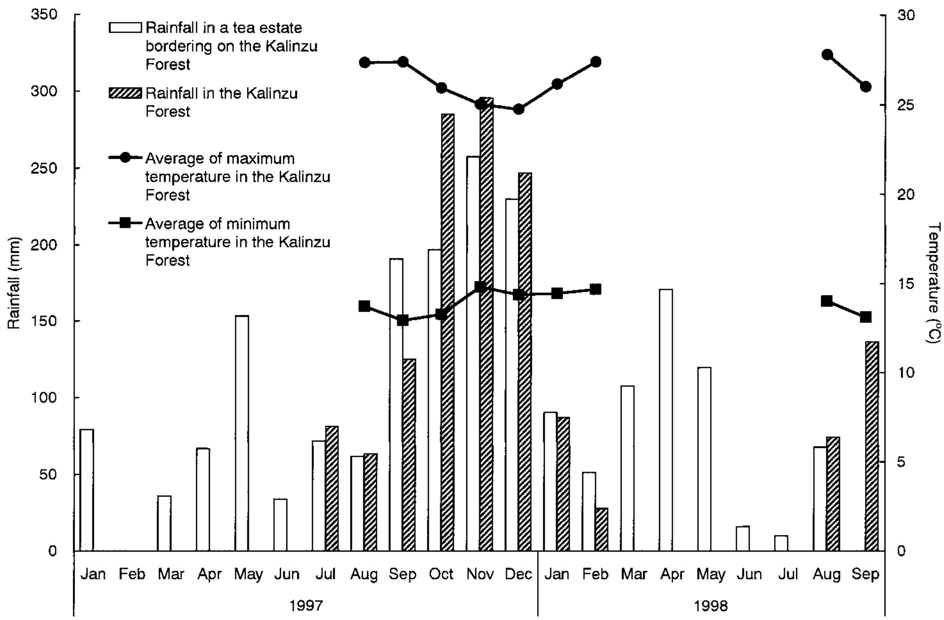

Fig. 1. Monthly rainfall and maximum and minimum temperature in the Kalinzu Forest. A blank bar indicates the rainfall measured in the tea estate bordering on the Kalinzu Forest. Absence of a bar indicates the absence of data for that month.

tively dry seasons (from the beginning of January to the middle of March, and from the beginning of June to the middle of September: Fig. 1). Annual rainfall from June 1997 to May 1998 was 1584 mm. The vegetation of the Kalinzu Forest is broadly classified as a medium altitude moist evergreen forest (Howard, 1991). The Nkombe Sawmill, a logging company, has been logging mechanically in a northeastern part of the forest since the early 1970s. They mainly harvested *Parinari excelsa* selectively. Also, local people have been logging some useful trees, such as *Carapa grandiflora* and *Funtumia africana*, in some areas near villages and roads. These logging activities created some patches of secondary vegetation in the Kalinzu Forest.

This study was carried out from July 1997 to March 1998. Ten parallel transects of 5 km long each (Fig. 2) were built. Distances between the transects were 500 meters. Another rectangular transect of 1.8 km was built around the sawmill to collect supplementary information.

Vegetation was assessed using the belt transect method (Bullock, 1996). All trees of more than 10 cm in DBH (diameters at breast height) within 2.5 m of each side from the transects were marked with plastic numbered tags. Species name and DBH of each tree was recorded. Most of the tree species were identified by the herbarium of the Makerere University in Uganda.

A principal component analysis was employed using a software STATISTICA for Windows Ver. 5.1. For the analysis of vegetation, each transect was divided into blocks of 5 m × 500 m (103 blocks in total). We used a number of trees of each species in each block as a variable for the analysis.

To make a comparison with the results of the above-mentioned analysis, visual

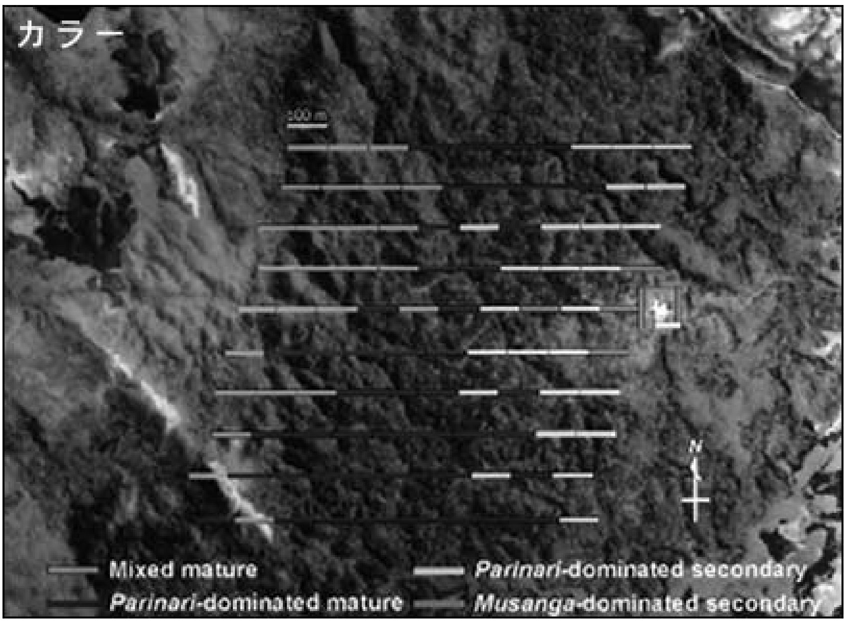

Fig. 2. Picture of the study area made from Landsat data and belt transects. The colors of each block in the transects show the vegetation type determined by this study.

characteristics of each block, such as the species name of dominant or prominent trees, and presence of traces of having been harvested mechanically in the past, were recorded. Also a picture of the study area was made using Landsat data (Fig. 2). The data used were from the Landsat Scene of Thematic Mapper sensor (south-east mini scene of path 173 - row 60, 88 km [North-South] × 93 km [East-West]), recorded on 20/08/1989. These data were analyzed by a program ERDAS Ver 7.5. A picture was synthesized by TM bands 5 (mid-infrared: 1.55 - 1.74 mm), 4 (reflective-infrared: 0.76 - 0.09 mm), and 3 (red: 0.63 - 0.69 mm) (Hashimoto et al., 1998). These three bands were represented by red, green, and blue respectively in the picture.

Data of vocalization of chimpanzees was collected for the preliminary analysis of

Table 1. List of tree species that were used as variables for principal component analysis.

Tree name	Frequency (%)	
Funtumia africana	68.0	*
Strombosia scheffleri	52.7	*
Craterispermum laurinum	34.1	
Dtypetes spp.	33.6	**
Cassipourea spp.	30.6	**
Celtis durandii	29.2	
Xymalos monospora	24.4	
Markhamia platycalyx	18.5	
Oxyanthus speciosus	17.7	
Beischmiedia ugandensis	16.5	
Pleiocarpa pycnantha	16.4	
Chionantthus mildbraedii	16.2	
Diospyros spp.	15.1	**
Dictyandra arborescnes	13.0	
Rinorea ilicifolia	12.2	
Parinari excelsa	11.4	
Carapa grandiflora	11.1	
Tabernaemontana odoratissima	8.8	
Trichilia rubescens	8.6	
Sapium ellipticum	8.0	
Unidentified spp. 2	8.0	**
Trema orientalis	7.7	
Ficus spp.	6.9	**
Uvariopsis congensis	6.9	
Musanga leo-errerae	6.7	
Trichoscypha submontana	6.3	
Unidentified sp. 1	6.3	
Trichilia volkensii	6.1	
Teclea nobilis	6.0	
Unidentified spp. 8	5.7	**
Myrianthus holstii	5.6	
Macaranga schweinfurthii	5.2	
Syzygium spp.	5.1	**
Pseudospondias microcarpa sp.	4.8	*
Erythrococca trichogyne	4.7	*

Frequency means percentage of plots including trees of each species
* = tree species omitted from analysis beacuase their frequency was more than 40% or less than 5%.
** = tree species omitted from analysis beacause more than one species is included.
Tree species whose frequency was less than 4% were not written in this table.

the relationship between the habitat use of chimpanzees and the results of this study. We walked along the transects 10 times each, and one point was given to a block if vocalization of chimpanzees was heard in the block, in each census. The points for each block were totaled for the 10 censuses, and used as an indicator of the use of the block by chimpanzees.

RESULTS

A total of 11,286 trees on all the transects was recorded. Of these trees, 96% were identified to the genus level and 78% were identified to the species level. The most dominant species, which had the largest total basal area, was *Strombosia scheffleri*, and it was distributed throughout the study area. The second most dominant species was *Parinari excelsa*, which was mainly distributed in the eastern part of the study area.

First, we examined the presence of trees of each species in each plot of 5 m × 50 m, which was one tenth of a block. Then, in order to exclude trivial variation and to avoid uniformity, 24 species that were found in more than 5% and less than 40% of all plots were used for the principal component analysis (Table 1). Analyses on the number of these tree species yielded eight components that had more than 60% of the cumulative contribution rate. We used two of these eight components (the first component and the second component) for further analyses. The cumulative contribution rate of these two components was 25.5%.

The first component was composed of large negative loadings in variables of tree species that were distributed in the western part of the study area (Fig. 3). Therefore, this component seemed to indicate the environmental factors that distinguished

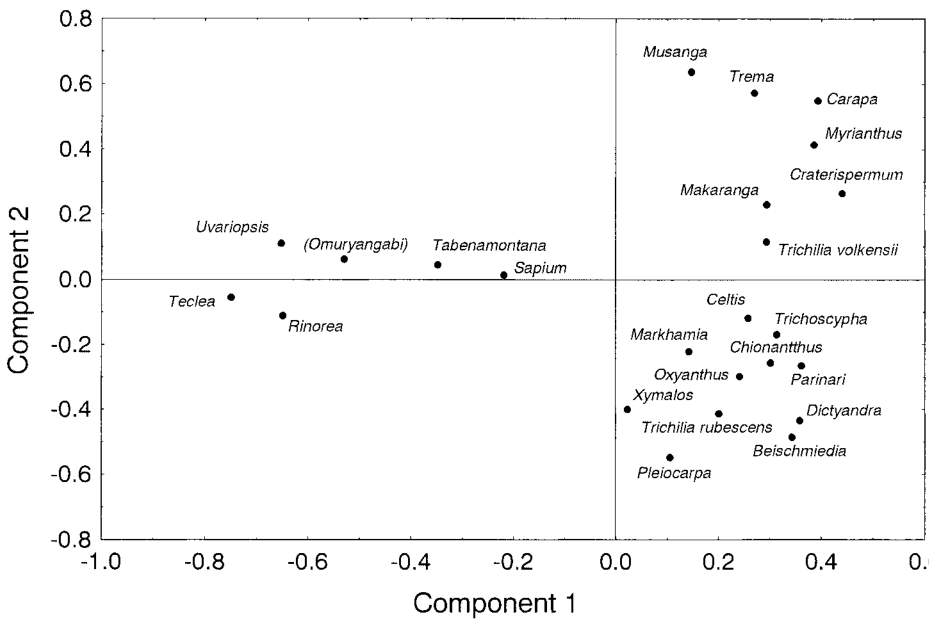

Fig. 3. Loadings of component 1 and component 2 of the 24 tree species used for the analysis.

between vegetation types of the west and east parts of the study area. On the other hand, large positive loadings of the second component were found in variables of pioneer tree species. Therefore this component seemed to indicate the extent of disturbance by human exploitation.

Principal component scores were calculated for each block (Fig. 4). Based on the distribution of the points for the first component, all blocks were split into two types. Blocks whose scores for the first component were less than -0.45 were

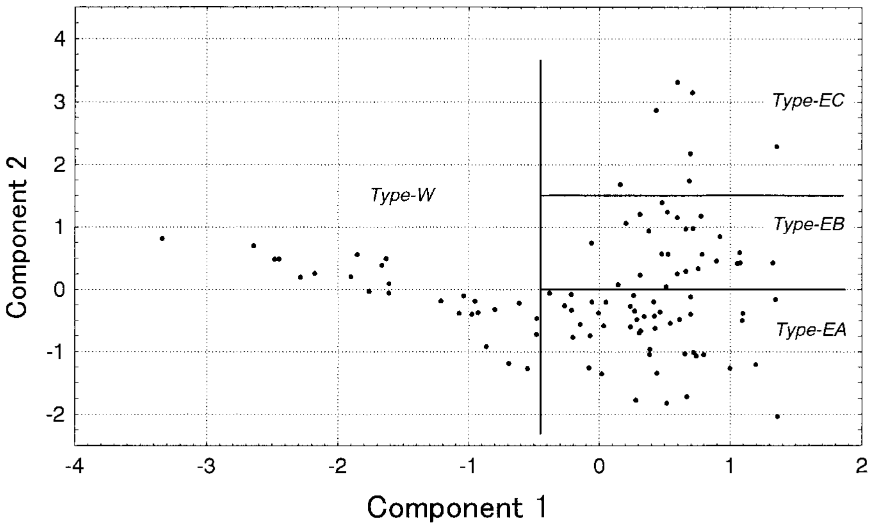

Fig. 4. Component scores for each block.

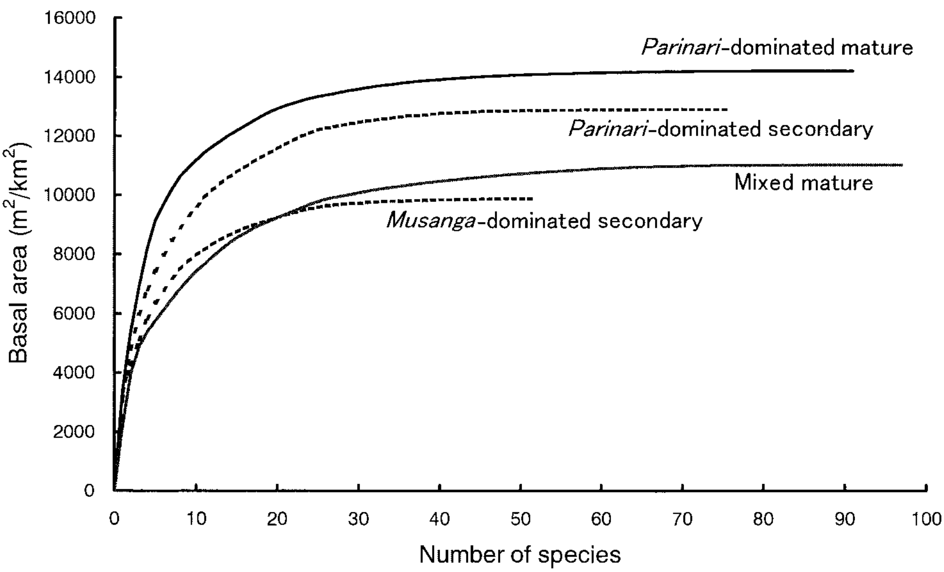

Fig. 5. Relationship between number of species and cumulative basal area in each vegetation type.

included in "type-W," which was the vegetation with factors characteristic to the western part of study area. Blocks whose scores for the first component were more than −0.45 were included in "type-E."

Type-E was then split into three types according to the scores of the second component. Blocks whose scores of the second component were less than 0, those between 0 and 1.5, and those of more than 1.5 were included in "type-EA," "type-EB," and "type-EC," respectively. The separation level of 0 was determined rather arbitrarily because there was no clear discontinuity in the distribution for the blocks (Fig. 4). We chose this level for separation because the traces of mechanical harvesting were mostly found in the blocks whose scores of the second component were more than 0.

Tree composition was compared between the above four vegetation types (Table 2). *Strombosia scheffleri* had a large basal area in all vegetation types. Therefore it was the dominant species of the whole study area. *Parinari excelsa* was codominant in type-EA and type-EB. These two vegetation types had similar tree species, but species that are characteristic to secondary forest, such as *Carapa grandifolia* and *Myrianthus holstii*, were mainly found in type-EB. Therefore, type-EA and EB were named "*Parinari*-dominated mature forest", and "*Parinari*-dominated secondary forest" respectively. Because type-EC was characterized by the largest basal area of *Musanga leo-errerae,* it was named "*Musanga*-dominated secondary forest." Because type-W did not have any prominent dominant species, it was named "mixed mature forest."

Fig. 2 shows the vegetation type of each block. Mixed mature forest was distributed in the western part of the study area. *Parinari*-dominated mature, *Parinari*-dominated secondary, and *Musanga*-dominated secondary forests were distributed concentrically around the sawmill. In the picture made using Landsat data, the two types of secondary forest could not be distinguished from each other: both were represented by light green. *Parinari*-dominated mature forest was represented by dark green and mixed mature forest was represented by medium green.

Fig. 5 (P.234) shows the relationship between number of tree species and cumulative basal area of trees in each vegetation type. The slope in the former part of each curve represents the extent of contribution of major tree species, and the terminal point on the right shows the total number of species and total basal area per square kilometer. As stated above, contribution of major trees was less in the mixed mature forest than in the other types of vegetation. The mixed mature forest had more tree species and less basal area than did the *Parinari*-dominated mature forest. This was because the mature mixed forest had more abundant medium or low trees, such as *Drypetes* spp., and the *Parinari*-dominated mature forest had many large *Parinari excelsa* trees (Table 2). Except for the mixed mature forest, there was a clear tendency for more disturbed forest to have fewer tree species and less total basal area. According to the Shannon-Weaver index of diversity H' ($H' = -\sum \frac{n_i}{N} \ln\left(\frac{n_i}{N}\right)$; N is the total number of trees, and n_i is the total number of trees for each species; Shannon & Weaver, 1949; Pielou, 1969), both types of mature forest had higher diversity than did both types of secondary forest (H' was 3.2 for *Parinari*-dominated mature forest and mixed mature forest, and 2.9 for *Musanga*-dominated secondary forest and *Parinari* dominated secondary forest).

Table 2. List of tree species in each vegetation type.

Scientific Name	NI/km²	RNI (%)	BA/km²	RBA (%)
a) Mixed mature forest				
Drypetes spp.	90000.0	19.4	2146.5	19.4
Strombosia scheffleri	2415.4	5.2	1787.9	16.2
Funtumia africana	4830.8	10.4	898.3	8.1
Diospyros spp.	3092.3	6.7	545.0	4.9
Warburgia ugandensis	553.8	1.2	370.2	3.4
Parinari excelsa	215.4	0.5	368.9	3.3
Pseudospondias microcarpa	246.2	0.5	360.6	3.3
Rinorea ilicifolia	3830.8	8.3	347.7	3.1
Celtis durandii	1169.2	2.5	322.9	2.9
Unidentified sp. 1	2569.2	5.5	281.2	2.5
Teclea nobilis	846.2	1.8	233.1	2.1
Markhamia platycalyx	615.4	1.3	231.4	2.1
Uvariopsis congensis	3015.4	6.5	230.8	2.1
Newtonia buchananii	138.5	0.3	213.8	1.9
Xymalos monospora	1630.8	3.5	198.1	1.8
Markhamia platycalyx	753.8	1.6	159.9	1.4
Unidentified sp. 2	323.1	0.7	156.8	1.4
Mimusops bagswawei	107.7	0.2	141.2	1.3
Unidentified sp. 3	15.4	0.0	124.0	1.1
Aningeria altissima	46.2	0.1	118.5	1.1
Unidentified sp. 4	200.0	0.4	117.7	1.1
Prunus africana	153.8	0.3	114.1	1.0
Monadora myristica	123.1	0.3	113.9	1.0
Cassipourea spp.	707.7	1.5	103.1	0.9
Unidentified sp. 5	815.4	1.8	94.5	0.9
Beischmiedia ugandensis	430.8	0.9	83.4	0.8
Unidentified sp. 6	15.4	0.0	53.3	0.5
Unidentified sp. 7	800.0	1.7	51.3	0.5
b) *Parinari*-dominated mature forest				
Strombosia scheffleri	4000.0	9.5	3392.1	23.8
Parinari excelsa	755.6	1.8	1982.7	13.9
Drypetes spp.	3022.2	7.2	1509.0	10.6
Funtumia africana	7697.8	18.4	1279.1	9.0
Celtis durandii	2071.1	4.9	968.3	6.8
Ficus spp.	204.4	0.5	558.0	3.9
Pseudospondias microcarpa	275.6	0.7	481.8	3.4
Cassipourea spp.	2577.8	6.1	443.4	3.1
Markhamia platycalyx	1484.4	3.5	283.9	2.0
Craterispermum laurinum	3848.9	9.2	279.1	2.0
Beischmiedia ugandensis	1013.3	2.4	251.3	1.8
Chionantthus mildbraedii	1155.6	2.8	202.1	1.4
Xymalos monospora	1653.3	3.9	190.8	1.3
Trichoscypha submontana	355.6	0.8	184.8	1.3
Diospyros spp.	728.9	1.7	169.9	1.2
Mimusops bagswawei	35.6	0.1	167.3	1.2
Aningeria altissima	44.4	0.1	165.6	1.2
Sapium ellipticum	240.0	0.6	157.2	1.1
Carapa grandifolia	275.6	0.7	151.2	1.1

continued

Scientific Name	NI/km^2	RNI (%)	BA/km^2	RBA (%)
c) *Parinari*-dominated secondary forest				
Strombosia scheffleri	3776.1	8.4	3087.2	23.9
Parinari excelsa	576.0	1.3	1696.7	13.1
Craterispermum laurinum	14240.0	31.7	1183.2	9.2
Funtumia africana	5632.0	12.5	839.4	6.5
Carapa grandifolia	1104.0	2.5	627.4	4.9
Celtis durandii	1264.0	2.8	534.1	4.1
Ficus spp.	688.0	1.5	483.3	3.7
Cassipourea spp.	2128.0	4.7	437.4	3.4
Drypetes spp.	496.0	1.1	418.7	3.2
Myrianthus holstii	608.0	1.4	317.5	2.5
Sapium ellipticum	432.0	1.0	276.2	2.1
Xymalos monospora	1056.0	2.3	250.2	1.9
Trichoscypha submontana	368.0	0.8	219.6	1.7
Macaranga schweinfurthii	1136.0	2.5	208.9	1.6
Markhamia platycalyx	720.0	1.6	177.6	1.4
Syzygium spp.	688.0	1.5	175.6	1.4
Beischmiedia ugandensis	656.0	1.5	173.6	1.3
Trema orientalis	832.0	1.8	160.1	1.2
Musanga leo-errerae	560.0	1.2	154.4	1.2
Chionantthus mildbraedii	1088.0	2.4	145.6	1.1
Neoboutonia cacrocalyx	496.0	1.1	144.8	1.1
d) *Musanga*-dominated secondary forest				
Musanga leo-errerae	7248.6	17.6	3340.3	33.8
Strombosia scheffleri	2171.4	5.1	909.4	9.2
Carapa grandifolia	2857.1	6.8	851.3	8.6
Funtumia africana	8285.7	19.6	733.1	7.4
Trema orientalis	2628.6	6.2	531.2	5.4
Craterispermum laurinum	3942.9	9.3	423.0	4.3
Celtis durandii	1885.7	4.5	414.5	4.2
Myrianthus holstii	1028.6	2.4	285.4	2.9
Parinari excelsa	114.3	0.3	254.2	2.6
Markhamia platycalyx	742.9	1.8	214.7	2.2
Macaranga schweinfurthii	628.6	1.5	171.8	1.7
Beischmiedia ugandensis	400.0	0.9	169.6	1.7
Ficus spp.	1542.9	3.6	162.5	1.6
Mitragyna stipulosa	171.4	0.4	148.3	1.5
Cassipourea spp.	742.9	1.8	135.8	1.4
Syzygium spp.	285.7	0.7	124.7	1.3
Diospyros spp.	171.4	0.4	96.7	1.0

NI/km^2: number of individual trees per km^2, RNI (%): relative number of individual trees, BA/km^2: total basal area (m^2) per km^2, RBA (%): relative basal area.
Tree species are listed in the order of RBA until the cumulative RBA reaches 90%.

To examine the availability of the component scores for the study of primates, we made a preliminary analysis of the relationship between component scores and habitat use of chimpanzees. There was a significant correlation between the scores of the second component of each block and the frequency of vocalization of chimpanzees heard in the block (Pearson's correlation coefficient, $r = 0.42$, $n = 74$, $t = 3.9$, $p < 0.0005$). This may indicate that chimpanzees used more disturbed vegetation with higher frequencies.

DISCUSSION

Ordination is a procedure for adapting a multidimensional swarm of data points onto a few dimensioned axes so that any intrinsic pattern of the swarm becomes apparent. In ordination by principal component analysis, it is important that the yielded axes are those which can be interpreted with actual ecological knowledge, because such analysis sometimes yields uninterpretable and meaningless axes (Pieleu, 1984). In this study, we got two easily interpreted components that fit observed characteristics of sample blocks: the first component seemed to indicate the environmental gradient that distinguish vegetation in the western and eastern parts of the study area, and the second component seemed to indicate the extent of disturbance of the forest in the past. Therefore, the distribution of data points on the scatter diagram was interpreted rather easily.

The relationship between some ecological traits of subject animals and the environmental gradient can be examined by using the score of the principal components. For example, this study showed the positive correlation between the frequency of chimpanzees' vocalization and scores of the second component in the east area, that may represent the extent of disturbance. The analysis using these principal components will reveal more important tendencies of habitat use of subject animals that are related to the environmental gradient.

If some points in the scatter diagram are in a close order, a group of those points can be regarded as a node that refers to the sample blocks resembling one another (Kobayashi, 1995). Therefore the scores of the principal component analysis may be used for making a vegetation map. Even if the vegetation changes continuously and there is no apparent discontinuity in a swarm of data points, such a swarm can be divided into two groups by setting some cutoff level, as far as those separated groups show some meaningful differences. In this study, for example, vegetation type-EA and type-EB that were separated by the level 0 of the second principal component showed different frequency of traits of harvesting, and different score of complexity. The vegetation map drawn by this study will be usefully applied to the ecological studies of primates in the Kalinzu forest, and those studies in turn will further examine whether or not those cutoff levels are meaningful.

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